Developing for non-human users: reflecting on practical implications in the ubiquitous computing era☆

Dirk van der Linden[a], Anna Zamansky[b], Irit Hadar[b], Barnaby Craggs[a]

[a] *University of Bristol, UK*
[b] *University of Haifa, Israel*

Abstract

Advances in modern technology, such as the Internet of Things (IoT) and ubiquitous computing, open up new exciting opportunities for technology for animals. This is evidenced by the explosion of products and gadgets available for pets, digital enrichment for captive animals in zoos, sensor based smart farming, etc. At the same time, the emerging discipline of Animal-Computer Interaction (ACI) marks a new era in the design and development of animal technologies, promoting a more animal-centric approach, considering the needs of the animal in the development process. In this article, we reflect on the ways in which ideas of animal-centric development may impact the development of technology for animals in practice. We start by looking at the process of development for and with animals, and propose a development model facilitating the principles of Agility, Welfare of Animals, and eXperts' involvement (AWAX) within the development lifecycle. While promoting the animal-centric approach, it is important to acknowledge that an animal usually uses technology through humans and in a particular environment. We further extend the AWAX model to include considerations of the human in the loop and the environment, and discuss some practical implications of this view, including aspects such as security and privacy.

Keywords: Animal-Computer Interaction, User-centered design,

☆This article is based upon early work published in JIT-RE'17 [1]

Email address: `dirk.vanderlinden@bristol.ac.uk` (Dirk van der Linden)
URL: `www.dirkvanderlinden.eu` (Dirk van der Linden)

1. Introduction

1.1. Background

Animals have been active users of technology for decades. Some prominent examples are artificial stimuli for studying animal behavior [2], telemetry and bio-logging for conservation of endangered species [3], etc. The advent of recent technologies opens up new exciting possibilities for animal users, but also calls for careful consideration of how and where these technologies should be developed and used.

One notable and yet understudied new direction in technologies for animals are pet wearables, such as smart tags, collars and vests for monitoring pets' well-being and health. According to a new market research report [4], the pet wearables market is estimated to reach over 3 billion dollars by 2025, a 13.5% growth from 2016. According to this report, "[the] increasing popularity of wearable technology for humans has paved way for various wearables for pets. In addition, with decreasing costs for various sensors, pet wearable manufacturers have been able to incorporate numerous features and functions into singular products at affordable prices. Other technological factors resulting in higher adoption of pet wearable technology include growing demand for smart connected homes." Wearables for pets are increasingly used by veterinary doctors to monitor the health of their patients, and insurance companies such as the RSA Group invest in wearables to gain access to health information of insured pets[1].

In parallel to the above developments in industry, in academia a new discipline of Animal-Computer Interaction (ACI) [5, 6] emerges, starting out as a subfield of Human-Computer Interaction quickly growing into a multi-disciplinary field. ACI marks a new era in designing technologies for animals by taking a

[1] `https://www.theguardian.com/lifeandstyle/2017/feb/03/wearable-tech-for-pets`

user-centric approach, placing the animal in the center of the development process. The field emerged five years ago with Mancini's manifesto [5], expressing concerns about the lack of animal-centric considerations in designing technologies for animals. The manifesto declares the aims of ACI as a discipline that develops a user-centered approach, informed by the best available knowledge of animals needs and preferences, to the design of technology that is meant for animal use. It also appropriately regards humans and other species alike as legitimate stakeholders throughout all the phases of the development process.

The agenda of ACI, putting the well-being of animals in the center of attention, is consistent with the new emerging directions of animal products on the market, such as pet wearables and digital zoo enrichment. However, while new technology for animals constantly emerge, they are often not systematically grounded in expert body of knowledge of animals needs and characteristics. Some of these products fail, not for the lack of proposed technological solutions, but for the lack of understanding their users[2]. And yet, the uptake of ideas, methods and approaches produced by the ACI community has arguably been slow so far. This may partly stem from the relative youth of ACI as a research focus; while some work had started earlier, the ACI manifesto in 2011 marked the beginning of a focused and greater attention paid to this topic.

1.2. Objectives

The aim of this article is to initiate a discourse toward bridging the gap between the animal-centric approaches advocated by the ACI research community and technology for animals developed by the industry. To this end we discuss the design of technology with which an animal interacts in terms of development processes. More concretely, we propose a model termed AWAX (Agile development, minding the Welfare of Animals and involving animal eXperts), which

[2]Some examples of such deserted initiatives are PlayDog (`https://www.letitmake.com/playdog`) and No More Woof (`http://www.nomorewoof.com/`). Other products, about which concerns have been raised with respect to the stress they might induce, are Dog Parker (`http://www.dogparker.com/`) and TailTalk (`http://www.dogstar.life/`)

stresses unique animal-centric aspects of the development cycle. However, much of the ACI research, dedicated to developing new technology, has been focused so far on technology actively used by the animals themselves (e.g., self-feeders, cognitive enrichment), and in doing so, has typically placed its focus exclusively on the animal. Yet an animal only uses technology through humans, on whose decision the technology has eventual impact. We therefore extend the view of the AWAX model to consider the technology for animal as a part of its environment, and discuss what this entails. We finish by discussing the unique challenges arising from the different types of interactions and propose a research road map for a further systematization of the field of technology for animals.

The rest of this article is structured as follows. Section 2 gives an overview of unique aspects of developing technology for and with animals, proposing the AWAX development model. We further explore the wider usage context of technology for animals in Section 3, setting out how this context leads to additional considerations for developers, and what may be done to deal with them. Finally, we conclude by summarizing and reflecting on what other challenges there may be out there in Section 4.

2. Animal-Centric Development

2.1. Technology for Animals

We view technology for animals (T4A), as opposed to animal-related technology, as those technologies that are developed with aims that are consistent with the goals declared in the ACI manifesto [5]:

G1 Improving animals' life expectancy and quality, by facilitating the fulfillment of their physiological and psychological needs (e.g., digital enrichment in zoos [7, 8]).

G2 Supporting animals in the legal functions they perform[3], by minimizing

[3] Animals' legal functions refers to the tasks animals perform that humans expect of them in daily social practices, such as dairy farming, working dogs, etc.

any negative effects and maximizing any positive effects of those functions on the animals' life expectancy and quality (e.g., technologies supporting working dogs in their tasks [9, 10]).

G3 Fostering the relationship between humans and animals, by enabling communication and promoting understanding between the two (e.g., games for reinforcing the human-animal bond [11, 7]).

A distinction between animal technology and ACI technology was made by Ritvo and Allison [12]. Animal technology includes any technology intended for animals, while ACI includes only that technology where animals directly interact with it. For example, an automatic milking system qualifies as an animal technology, but not as ACI technology. However, a voluntary milking system qualifies as both an animal technology and an ACI system as it allows the animal to self-determine and initiate milking times via an animal-initiated interaction with an interface.

We believe that the focus of research efforts should not be limited solely to technologies where animals initiate direct interaction with the devices. While it is surely a very interesting and challenging aspect from an ACI point of view, technologies like the voluntary milking system are of little practical interest in the farming industry. Moreover, even indirect interactions of animals with technology pose challenges towards their usability (consider, e.g., TailTalk vs. Fitbark, two types of dog wearables, one intended to be put on the dog's collar, and the other intended to be strapped around the dog's tail). Therefore, animal-centric approaches towards technology development are potentially useful even when no direct interaction between the animal and the device occurs.

One illustrative example of promoting an animal-centric approach in this context is bio-logging, the practice of tracking and monitoring animals. As highlighted by Hawkins [13]: "Telemetry and datalogging (referred to as bio-logging in this article) are often regarded as techniques that can benefit both science and animal welfare. However, it is essential to remember that the application of bio-logging involves procedures that can cause animals pain, suffering and distress. The technique therefore needs to be refined to reduce any pain, distress and suffering, just like all other experimental procedures on living animals." Following these guidelines is, however, a non-trivial task, even with the involvement of a team of highly-experienced animal experts.

Cid *et al.* [14] describe fatal injuries of agouti (a type of rodent) as a result of the use of radio-telemetric collars used during reintroduction efforts in a National Park in Brazil. The initially designed collar was heavy and uncomfortable, causing the agoutis to scratch their necks, which resulted in infections due to the rainy climate. The collar was redesigned to prevent this unintentional behavior, by reducing its width and choosing a less water retentive material.

Another example, provided by Paci, Mancini and Price [15] involves a study on the wearability of commercial tracking systems for cats. This study revealed major annoyances experienced by the cats, such as itchiness and irritation, caused by the cat scratching due to the presence of the collars. The authors note on unintended, yet perhaps foreseeable risks, that "while attempting to remove the device, the cat compromised his balance and risked falling off the [dangerously high] tree perch."

In their ethical reflections on the animal-centered goals of ACI, Grillaert and Camenzind [16] noted: "Here we arrive at a point of conflict between the non-speciesist ethical claim of ACI and the current speciesist practices within its fields of implementation. ACI proclaims an equal moral standing for animals, and that "ACI is not about doing research 'on' animals but about working 'with' animals in order to benefit them without harming the individuals involved in the process." This position is more rigorous than, and conflicts with, the common welfarist approaches of farming or animal experimentation domains, which shorten animal life expectancy, lower quality of life, and allow invasive practices. Rather than an accusation of inconsistency or bigotry, this reflection represents a starting point for a reevaluation of ACIs ethical approach, its role and responsibilities in society, and also its future directions."

Thus, perhaps the ACI-inspired commitment to animals to "build only what they want or need" [17] is not so easy to keep in practice. Working dogs may not *want, or care for* the wearable communication devices their owners attach to them, and cows on a dairy farm may not *want* the milking system (voluntary or otherwise). However, using animals in these ways is a common social practice. As such, we can make a commitment to minimize the negative effects of the ways in which animals are used while maximizing their welfare and well-being, in compliance to Goal G2 above.

There is room for animal-centric considerations even in situations where an animal finds itself in conditions that are not optimal with respect to its needs. For example, Nannoni *et al.* discuss enrichment for heavy pigs intended for ham production [18]. The authors highlight the European legislation that requires the provision of materials to play with for pigs of all ages, and reflect on ways technological interventions could provide practical solutions to increase the well-being of pigs used in heavy pig farming.

While perhaps in the distant future systems in which animals directly interact with devices and control their environment (such as voluntary milking systems [12] or smart kennels [19]) will become a widely used reality, currently such systems have low economic impact and consequently are of little interest to the farming and pet technologies industries. Given the technology available on the market now, and the ways animals interact with it, we believe that the ideas of (animal) user-centric approach are applicable, and worthwhile to pursue for any technology for animals which is compliant with the goals G1–3 described at the start of this section.

2.2. What is special about T4A development?

Developing T4A is unique in the sense that involving animals as users and stakeholders places rigid demands on all phases of the development process. We have discussed these challenges in earlier work [17, 20], focusing on requirement elicitation with non-human users, communicating with animal experts and handlers, and searching for innovative ways of getting feedback from animals. In what follows we focus on three aspects that form the basis for the proposed development model: agile development, animal welfare considerations, and involving animal experts.

2.2.1. *Agility and rapid prototyping*

As a consequence of the difficulty of conversing with animals and asking what they want or like, the natural form of development is building artifacts and checking their appropriateness by *iterative prototyping.* Indeed, such prototype-oriented agile development seems to be the prevalent technique in the literature of ACI. Variations of this development method were used, e.g., for designing sensor-based canine interfaces [21, 22, 10] and for designing enrichment for elephants and apes kept in captivity [23, 8, 24].

Working iteratively is particularly important for enabling the gathering of feedback from an animal involved in the development process. As pointed out by French, Mancini, and Sharp on their experience developing technology with an elephant [8]: "As we did not know what types of controls an elephant was capable of using, nor what kinds of output held interest for her, it was vital to obtain feedback from Valli [the elephant] during the design process. This led us to prototype iteratively until a useful solution was reached." Mancini *et al.* [21] further note their reliance on iterative development by getting feedback from a dog's behavior: "We also had to find a way of stabilizing the stand to prevent it from being pushed back by the dog and thus dispersing the pressure we wanted to record."

2.2.2. *Welfare Considerations*

As mentioned in the previous section, T4A are technologies compliant with the goals declared by the ACI manifesto, the essence of which is minimizing the harm and maximizing the positive value introduced by the technology. However, operationalizing these goals turns out to be extremely challenging. The examples of agoutis injured by telemetric collars [14], cats irritated by such collars risking to fall off the tree perch [15], or dogs becoming overstimulated and even aggressive when playing digital games [25, 26] demonstrate the need to develop (and follow) more structured guidelines of harm-benefit analysis. Grillaert and Camerzind provide some hints in this direction [16], stressing the importance of monitoring the welfare of animals outside of laboratory settings and consumer trials.

2.2.3. Active involvement of animal experts

Another important aspect is the necessity to rely on the body of knowledge of animal experts, both for generating possible solutions and for testing them. In fact, in most cases it is practically impossible to develop a T4A without actively involving animal experts for several reasons. Firstly, one needs to have at least some degree of understanding about the physiology of the exact species for which the technology is being developed. Physiological features vary between species, and may differ significantly from ours - human's - such as color vision, pupil shape, and field of view. According to Zamansky *et al.*'s report on the 1st. Int. Workshop on Research Methods in ACI [27], "presenting an animal with a task that it cannot complete because it does not have the physical and/or perceptual capability will lead to inaccurate conclusions and will be detrimental from an animal welfare perspective." Moreover, recent work suggests that even animal scientists cannot be sure they understand the visual perception of dogs when designing and interpreting experiments [28].

Secondly, even within the context of developing for only one species, there is a large potential breed variety. This first manifests in terms of physiological difference. For example, when developing technology for dogs, one has to ensure that the technology is usable for the tiniest of dogs to the largest of them. More detailed physiological aspects also need to be accounted for, such as the physical location of a Pug's eyes compared to a Saluki entailing significant differences in their field of view, and therefore perception, e.g., of images projected on screens. As explained in the aforementioned report [27]: "From the perspective of behavioral science, it is important to take full account of the ecological niche and innate behavioral tendencies, perceptual abilities, and social needs of the species in question, and the impact that past human interactions (and other experiences) may have on an individual animal. In addition, the size and shape (anatomy) of the species and the age of the individual animal must be taken into account."

Besides the physiological diversity, taking into account the character diversity of animals is important as well. For example, in the Microsoft project at the Melbourne Zoo for digital enrichment for orangutans [7], researchers are working with the zookeepers to understand the different personalities of the zoos orangutans in order to design the atual way in which they interact with the technology, and increase their motivation to play[4]. Another example of the expression of individual characteristics is the work of Baskin *et al.* [26], who investigated the different reactions that dogs of similar breeds showed while playing tablet (video) games, likely due to character and personality differences.

Thus, animal experts must take a much more pivotal role in development processes than usual domain experts – functioning as a sort of surrogate stakeholder for the animal (analogous, for example, to the use of proxy customers in some forms of agile development, when no customers are directly available). While the latter inform the design process, the former rather guide it, and any development model should make explicit the points at which their expertise affects design decisions.

2.3. The AWAX development model

This section presents the synthesis of the considerations needed while developing T4As, namely agile development, minding animal welfare, and active involvement of animal experts at all stages of the development process. This leads to the proposed AWAX[5] model, which is shown below. The *agile* nature of the development cycle, as well as the involvement of different stakeholders, are captured on Fig. 1.

The envisioned collaboration between animal experts and the development

[4]See `https://pursuit.unimelb.edu.au/articles/kinecting-with-the-orang-utans`
[5]AWAX stands for Agility, Welfare of Animals as value and animal eXpert involvement.

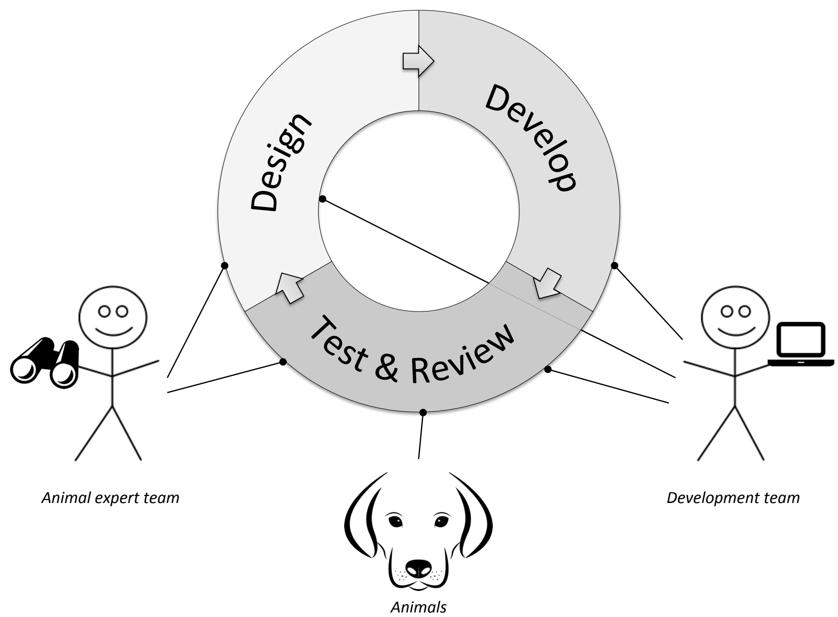


Figure 1: Diagram showing the cycle of AWAX development and the involvement of relevant stakeholder (teams) in each phase.

team is captured on Fig. 2: The animal team *guides* the development process (as opposed to just informing design as usual for domain experts) at the phases of design, test and review the developed technology, acting as a surrogate stakeholder for the animal, representing their interests to the best of their ability. Tasks placed on the dotted line are collaboratively executed, as can be seen from the stakeholder involvement.

When starting a project, an initial specification is typically derived from requirements imposed by business or research stakeholders. This tends to involve few *a priori* requirements specific to the animals, because very few reusable existing requirements fragments and patterns currently exist. This is further complicated because, as discussed in Section 2.2.3, requirements tend to differ between species (e.g., dogs, cats, elephants), and may be additionally fragmented between breeds with distinct physiological characteristics.

The points at which welfare considerations are explicitly reviewed by the an-

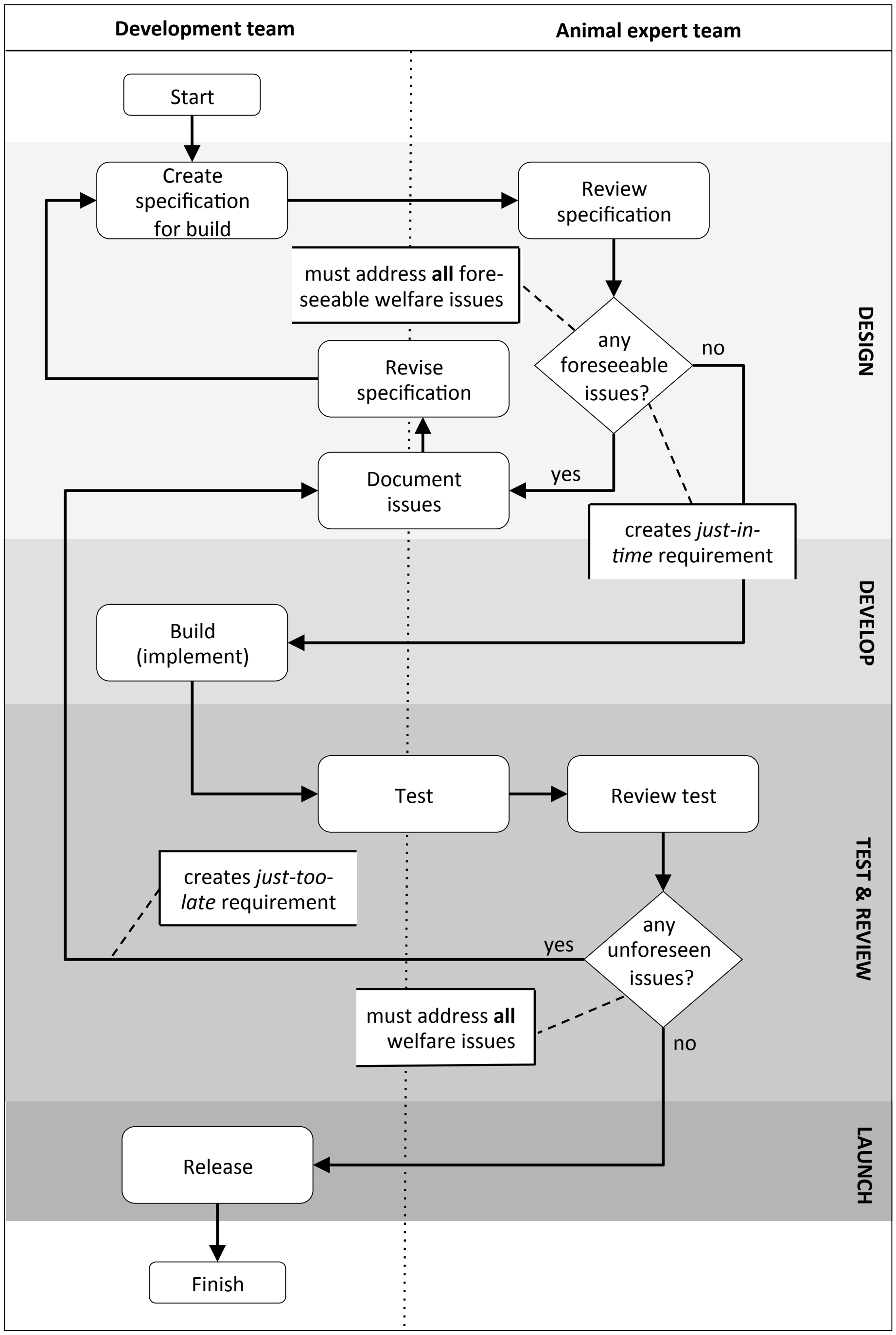


Figure 2: The **AWAX** (Agile, Welfare of Animals, eXperts) iterative development model for development of interactive animal technology.

imal expert team are also marked in the AWAX model. Welfare aspects noted at the initial point, together with other aspects of usability (e.g., determining more effective ways for the animal to interact, to make them want to use the technology) yield requirements for the current iteration. When testing a build of the technology, interpretation of the animal's interaction with the build will likely lead to unforeseen challenges in terms of usability, or unforeseen challenges impacting their welfare (e.g., unwittingly causing undue stress for the animal, or unforeseen safety issues - see the discussion below). This yields requirements, which, while having impacted the involved animal's well-being at that point, can contribute to avoiding them in the next iterations of the technology development.

While taken separately, the elements of the AWAX model are not conceptually novel in their own right, the main purpose of AWAX is to bring together and highlight the specific aspects unique to developing for animals that require special attention. Descriptions of practices in development of technology for animals are still scarce, mainly coming from the academic field of ACI. However, existing work that documents and reflects on ACI development processes, highlight the AWAX elements.

In a project for developing wearable interfaces for working dogs, Jackson et al. [10] performed a pilot study to explore with which sensors dogs can better interact with (e.g., in terms of accuracy and training). They created several sensors that allowed different ways of activation (biting, tugging, and nose gestures) for testing which sensors can be activated by dogs more reliably, leading to the *rapid prototyping* of different sensors, based on natural dog behaviors. French et al. [23] describe similar methods used in a project with an aim was to develop a technology for cognitive enrichment of captive elephants. As traditional approaches from HCI and UX design failed, the authors turned to rapid prototyping as a tool: "We offered real artifacts to elephants (and their keepers), then made observations. This involved many design iterations, as well as planning and implementing a series of prototypes to be tested in the field." [29] *Active involvement of experts* is reported by e.g., Gupfinger and Kaltenbrunner [30], who presented initial work towards auditory interfaces for grey parrots while actively consulting with experts to interpret the exact behavioral response of parrots to different musical stimuli.

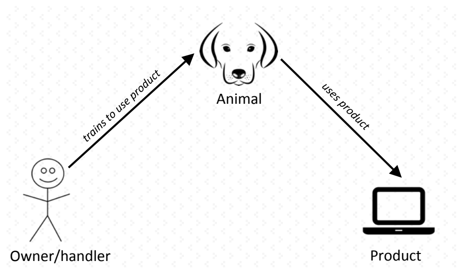
Our vision for the AWAX model is, therefore to additionally serve as a model for knowledge sharing and comparison of experiences in the T4A field.

3. The Wider Context of Technology for Animals

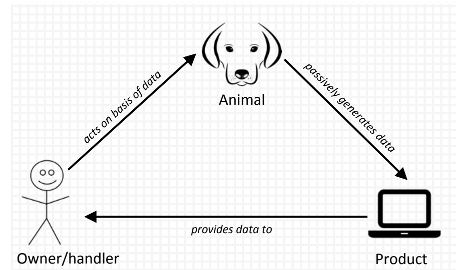
3.1. Different T4As, Different Context-of-Use

While the AWAX model provides ways to think about how to design technology for animals, there are important design considerations that can only be clearly understood when looking at the wider actual context-of-use of a developed technology. A technology designed to support animals in their legal function, or foster the relationship between humans and animals – major goals of T4As as described in Sec. 2.1, necessarily involves a wider context than just the animal. The (direct or indirect) interaction between an animal and the technology does not happen in a vacuum or a laboratory setting [16], but involves at least the animal's owner or handler, and possibly a much wider spectrum of such actors.

Figure 3 presents a typical context-of-use of a T4A, showing the different interactions that occur depending on the type of technology. While in Fig. 3(a)'s case the human trains the animal to use the technology, and the animal then uses it, there is no clear or direct interaction between the human and the technology. In the case of animal-worn technology, however, as shown in Fig. 3(b), the animal interacts (whether actively or passively) with the technology, and the human interacts with the animal in a way that is mediated by the technology. This mediation is predisposed on suggestions or interpretations of the data the technology generates, i.e., the owner or handler reads out data from the T4A and acts accordingly. As noted, this places further demands on producing such technology: whatever data it generates should be accurate and properly interpretable in order to lead to actionable decisions.



(a) Animal-used technology (e.g., pet self-feeder)



(b) Animal-worn technology (e.g., pet activity tracker)

Figure 3: The wider context of T4A: increased complexity of animal-worn technology feedback loops (Fig. 3(a)) as compared to animal-used technology (Fig. 3(b)). A feedback loop is established in animal-worn technology that places further demands on the technology.

As with wearables and humans, T4As worn by animals form a cyber-physical system (CPS), comprised of three core components. The digital software (on a device, a smart phone or the cloud), physical hardware (e.g., a collar for location tracking or behavior correction) and, in human factors and ergonomics terms (HF/E), liveware – the animal. Within this domain, it should be noted that the liveware may also include humans, in a type of symbiotic relationship with the animal, for example a pet and its owner.

This leads to a multitude of relationships between actors on different levels – let alone their use of any data. Figure 4 gives an overview of typical actors and interactions in the context of the most common pet wearable – activity trackers. It shows the levels of complexity at which the T4A is actually used.

On the first level of use, there is simply the animal wearing the actual technology. The use of data generated by that use to intervene in the animal's behavior is on the higher, second level, incorporating the owner. This constitutes the typical animal-human companionship relation. In this space, the data generated by the device worn by the animal (i.e., the activity data, location data) also typically resides in a device physically owned by the animal's owner (i.e., locally stored on their phone). However, in many cases the data would be stored in the cloud, through services offered by the producer of the technology,

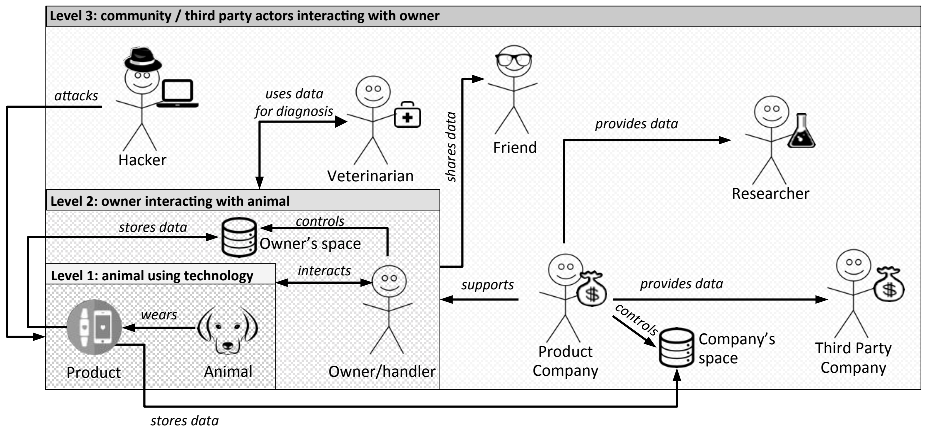


Figure 4: The three main levels of animal-worn technology for animals: the animal and the technology (level 1), the animal's companion interacting with that animal (level 2), and the wider community of other (potentially malicious) actors (level 3) interacting either with level 1 or 2. The increased scope of access to, and use of, data provided by the technology place further demands on it: generated data should be secure and private.

scaling up the context to the third level: the wider community of third party actors interacting either with the owner, or directly with the animal.

This includes direct interactions, and indirect interactions. Direct interactions are, for example, the exchanging of data between friends, or using the generated data at a visit to the veterinarian. Unnoticed one-sided interactions can be a malicious hacker attempting to intercept data directly from the animal wearing the device, or by attacking the data storage. A less obvious indirect interaction common to pet activity trackers is the use of data generated by the wearable by third parties, where the product company provides data either to commercial third parties for e.g., targeted advertisements, or pet health insurance, or provides such data to researchers and scientists collaborating with the product's company.

Having noted the importance of ensuring that T4A-generated data is accurate and appropriately interpretable, Fig. 4 further shows that ensuring the security and privacy of such data is an important consideration during the development of a T4A. These two aspects require developers to think about the potential impact of the technology they develop, descriptive examples of which are given in the following section.

3.2. What is special about T4A context?

3.2.1. Accuracy and Interpretability of T4A-suggested Interventions

Despite the explosion of pet wearables on the market, which provide data to pet owners in order to understand and intervene in their pets' behavior, there has been little work towards scientific validation of the data and the derived recommendations these products make to users. Looking at the number of potential actors that may (in)directly affect the animal user on basis of such data (see Fig. 4), this problem spans both personal (e.g., an owner changing the frequency of walks with their dog) and professional (e.g., a trained veterinarian suggesting to change the frequency of walks with their dog) interactions. If informed decisions are to be made on the basis of the collected data, e.g., vets deciding on treatment, or insurance companies deciding on insurance policies, there is a need for more systematic approaches to the validation of accuracy of data obtained from pet wearables.

This is directly related to AWAX's call for expert involvement, as going from raw data (e.g., movement duration and velocities) to interpreted data (e.g., classified behaviors such as 'resting', 'play', 'run') requires in-depth understanding of that particular species' and in some cases, breeds' idiosyncrasies. Thus, in the development stage of a T4A it should be made explicit whether suggestions for interventions in the animal user's behavior are desired, and if so, experts should be involved in the design of any algorithms to that extent.

A more troubling matter, of which developers of T4As need be aware, is the potential impact of their intervention suggestions, and the extent to which they may override expert suggestions. A study by Lawson et al. [31] showed that pet owners do not tend to question the outputs of the T4As, such as dog activity trackers, even valuing the output of the technology over the professional opinion of their veterinarian.

This means that, regardless of how accurate the generated data may be, it still has to allow for laymen to interpret it correctly. This may be more difficult than imagined, as studies have shown that pet owners tend to misinterpret their pet's very behavior [32], let alone their interactions with technology [33]. Given this trend of misinterpretation, the ability of owners or handlers to make decisions upon data received from pet trackers should be further studied.

3.2.2. Security and Privacy of T4As and their Data

As with any CPS, each of its components presents a risk to the safety and security of the other components, and most importantly each also has a role to play in the defense of the others [34]. At the simplest level, the physical component presents a safety concern best catered for by HF/E approaches to its design. In the case of animals, this is likely the domain of species-experts rather than a software or product engineer, as in the previously discussed case of tracking devices for Agoutis [35]. However, there are many security concerns that have been observed with in other CPS that occur in T4As.

An obvious example is privacy. Avoiding the philosophical arguments around whether animals want, need or deserve privacy, there are potential privacy risks for humans in the role of a pet owner. By the very nature of the dog-human relationship, tracking a dog on a daily walk implies that the human accompanying that dog is also being tracked (analogously to situation to tracking a smartphone which never leaves an owner's side). Whilst this may appear innocuous, the reality is that where data is collected about enough dog movements it is plausible that individual humans can potentially be identified. This is a privacy concern that requires investigation, having potential ramifications for areas such as insurance [36], urban-planning [37], and so on.

Privacy has been discussed thoroughly in the context of wearables (cf. [38, 39, 40]), but little has been thought specifically of the case of the animal-mediated indirect threats to human privacy we described. Looking at what has been done, some discussion on the privacy impact of human wearables poses questions that need critical thought in the animal-human CPS. For example, some governmental committees in the United States have recommended to consider issuing comprehensive regulations to prohibit deceptive and unfair advertising. However, as Marrington, Kerr, and Gammack noted, what would be considered deceptive or unfair is a difficult matter to define [41]. In the case of animal activity trackers, would it be deceptive for advertisement to focus on the animal user, foregoing the privacy consequences of human user? These are matters that require more attention for ongoing and future commercial developments of technology for animals, in particular wearables, to be steered in the right direction.

Moreover, in recent decades the advance of personal technology has already led to clearer insights into their privacy impact. The most salient example in this context is the case of mobile phones: our personal mobile phones are with us practically at all times. This means that tracking a mobile phone is not merely tracking a device, but tracking the person who owns the device. This context of use has a host of practical and legal implications from safety and privacy points of view [42]. In the same sense, fitness wearables used by humans have led to several privacy implications that required rethinking their design [40]. Technology for animals, similarly, has to go through such evolution as their contexts of use and the derived implications on our privacy and safety becomes clearer. For example, the ability to detect when (and potentially where) a person walks their dog would significantly enhance a burglar's data collection capabilities, as field observations can be replaced by simpler (and less risky) data examination.

Another type of challenge can be related to the protection of proprietary information in the context of agriculture. Let us consider a case of a farm who perfected its cows' life routine for the production of exceptionally high-quality milk. Hacking a device holding data about this routine would enable access to this proprietary information, enabling industrial espionage. The security concern stemming from the potential of hacking an animal wearable device holding data about its routine, behavior or health indicators, goes beyond mere access to data. Imagine a malicious hacker who changes the data residing within this device in order to interfere with the animal's routine, provide false data about it to the insurance company, or any other malicious intention. Such security breach can potentially harm the animal, its owner, or both.

Additional security concerns in agriculture can be found in the use of smart, sensor-based fencing for controlling herd movement. For example, in the dairy-farming context, a herd of cows can be constrained by a virtual fence (cf. [43]) by a wearable giving a negative audible or electrical stimulus when attempting to cross the sensor-defined area they are supposed to graze in. A malicious attacker could attempt to either remove or alter the parameters of the virtual fenced area, allowing the cattle to wander off and/or graze in areas suboptimal in terms of milk production. This would require significant time for the farmer to detect and physically correct, negatively impacting on the farm's productivity.

Such security concerns are perhaps more pressing in how they can directly affect the animal's health, as the risk exists that some wearables – those that give e.g., sonic or electric feedback – could be turned against the animal's well-being by a malicious attacker. Imagine a device that gives negative (ultra)sonic feedback to a dog when it barks, hacked by a malicious user to constantly emit the negative feedback. Given the grim situation of human cruelty towards animals [44, 45], such scenarios should be seriously considered in the design phase of such technology.

3.3. The AWAX addendum: development mindsets

Given that not all concerns discussed above are valid for all possible types of T4As, we opt to discuss ways to address such concerns via changes in the development mindset. Short of dictating ways to work, there are some well-advocated approaches which could be adopted by developers and guide their designs.

From a privacy perspective, T4A could be be guided by existing approaches for privacy, such as the highly advocated Privacy by Design (PbD) approach [46]. PbD calls for embedding privacy into the design of technologies at early stages of the development process and throughout its lifecycle; for example, embedding the principles of minimal and specific-purpose data collection. PbD is reflected by policy makers globally including the U.S. Federal Trade Commission [47] and in the EU's Regulation (EU) 2016/679, better known as the General Data Protection Regulation (GDPR) [48], which will become enforceable across the EU from the 25th of May, 2018. Importantly, despite the apparent simplicity of the idea of PbD, a major challenge for its successful deployment is translating the general abstract notion and the meaning of informational privacy into concrete guidelines for software developers [49, 50, 51]. Adding the indirect effect of T4A on animals' human owners or companions, would add further to the complexity of this challenge. Therefore, a promising future research direction would be to develop concrete PbD guidelines for designing privacy-preserving T4A.

Securing the system as a whole is arguably a harder challenge, however it is one which may lead not only to more secure systems, but also to better privacy outcomes. Craggs and Rashid [52] propose a more HF/E approach to building secure CPS. Rather than taking the more traditional route of bolting security on as an afterthought, by embedding their Security Ergonomics by Design principles into the development lifecycle, software engineers are empowered to "pragmatically take into account how users make informed security choices about their data and information in such a pervasive environment."

Such foundational principles are critical for T4A to ensure that design flaws (latent failures) in the system never align with the inevitable errors that the human developers and users make. An example of this lays within the identified potential privacy concerns above. Arguably these are a result of users not being aware of a need, or merely failing, to take suitable action to protect their own privacy when using T4A. By using security ergonomics design principles, this human error could be mitigated by the developer. For example, principle 3 (encourage secure behaviors) talks to the role software engineers should play in guiding users into taking suitable action, and principle 4 (non-alignment) would provide a safety-net for users by not allowing a failed or erroneous action to coincide with a property of the system which might expose privacy. Principle 5 (external validation) provides the software engineers something of a safeguard in recognizing that they themselves are prone to human error and thus require security related development decisions to be checked by third parties.

4. Concluding Outlook

The rapid advance of new technologies for animals, together with ACI maturing as a scientific discipline, make this a timely moment to reflect on the methodological foundations of developing technology for animals, and on how ideas and approaches from the ACI research domain can be adapted to the mass production of technologies in industry.

In this article, we took a step in this direction by proposing a development model for (software-intensive) technology for non-human users, which incorporates iterative prototyping, makes reference to animal welfare considerations, and is guided by active involvement of animal experts. We also demonstrated the importance of identifying and addressing the unique challenges of developing technological products for animals in the wider context of the environment in which both the animals and their owners operate, such as data accuracy, data interpretation, security and privacy. It is our hope that this can be a starting point for a cross-fertilization between industry and the research discipline of ACI, and the starting point for developing systematic yet pragmatic approaches for the development of technology for (and with) animals.

Moreover, there are ample directions of research that may contribute to the maturation of T4A development. The establishment of clear guidelines for the documentation and systematic re-use of requirements patterns and fragments is an important direction to lower the R&D efforts of developing new T4As, especially in the context of determining how requirements may be re-used from one species to another.

References

[1] D. van der Linden, A. Zamansky, Agile with animals: Towards a development method, in: Just-In-Time Requirements Engineering (JITRE), 2017 IEEE Workshop on, IEEE, pp. 475–481.

[2] B. Webb, Using robots to understand animal behavior, Advances in the Study of Behavior 38 (2008) 1–58.

[3] S. J. Cooke, Biotelemetry and biologging in endangered species research and animal conservation: relevance to regional, national, and iucn red list threat assessments, Endangered species research 4 (2008) 165–185.

[4] Credence Research, Pet Wearables Market By Technology (GPS, RFID, Sensors), By Product (Smart Tags, Smart Collars, Smart Vests) - Growth, Future Prospects, And Competitive Analysis, 2017–2025, http://www.credenceresearch.com/report/pet-wearables-market, 2017. Online; accessed 04 December 2017.

[5] C. Mancini, Animal-computer interaction: a manifesto, interactions 18 (2011) 69–73.

[6] C. Mancini, O. Juhlin, A. D. Cheock, J. van der Linden, S. Lawson, Animal-computer interaction (aci): pushing boundaries beyond 'human', in: Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational, ACM, pp. 833–836.

[7] S. Webber, M. Carter, S. Sherwen, W. Smith, Z. Joukhadar, F. Vetere, Kinecting with orangutans: Zoo visitors' empathetic responses to animals? use of interactive technology, in: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, ACM, pp. 6075–6088.

[8] F. French, C. Mancini, H. Sharp, Exploring methods for interaction design with animals: a case-study with valli, in: Proceedings of the Third International Conference on Animal-Computer Interaction, ACM, p. 3.

[9] C. Zeagler, C. Byrne, G. Valentin, L. Freil, E. Kidder, J. Crouch, T. Starner, M. M. Jackson, Search and rescue: dog and handler collaboration through wearable and mobile interfaces, in: Proceedings of the Third International Conference on Animal-Computer Interaction, ACM, p. 6.

[10] M. M. Jackson, G. Valentin, L. Freil, L. Burkeen, C. Zeagler, S. Gilliland, B. Currier, T. Starner, Fido – facilitating interactions for dogs with occupations: wearable communication interfaces for working dogs, Personal and Ubiquitous Computing 19 (2015) 155–173.

[11] P. Pons, J. Jaen, A. Catala, Developing a depth-based tracking system for interactive playful environments with animals, in: Proceedings of the 12th International Conference on Advances in Computer Entertainment Technology, ACM, p. 59.

[12] S. E. Ritvo, R. S. Allison, Designing for the exceptional user: Nonhuman animal-computer interaction (aci), Computers in Human Behavior 70 (2017) 222–233.

[13] P. Hawkins, Bio-logging and animal welfare: practical refinements, Memoirs of National Institute of Polar Research. Special issue 58 (2004) 58–68.

[14] B. Cid, R. d. C. d. Costa, D. d. A. Balthazar, A. M. Augusto, A. S. Pires, F. A. Fernandez, Preventing injuries caused by radiotelemetry collars in reintroduced red-rumped agoutis, dasyprocta leporina (rodentia: Dasyproctidae), in atlantic forest, southeastern brazil, Zoologia (Curitiba) 30 (2013) 115–118.

[15] P. Paci, C. Mancini, B. A. Price, Designing for wearability in animal biotelemetry, in: Proceedings of the Third International Conference on Animal-Computer Interaction, ACM, p. 13.

[16] K. Grillaert, S. Camenzind, Unleashed enthusiasm: ethical reflections on harms, benefits, and animal-centered aims of aci, in: Proceedings of the Third International Conference on Animal-Computer Interaction, ACM, p. 9.

[17] A. Zamansky, A. Roshier, C. Mancini, S. North, C. Hall, E. Collins, K. Grillaert, A. Morrison, A report on the first international workshop on research

methods in animal-computer interaction, in: CHI'17 Extended Abstracts, ACM.

[18] E. Nannoni, G. Martelli, L. Sardi, Enrichments for pigs: Improving animal-environment relations, in: Animal-Computer Interaction, ACM.

[19] C. Mancini, J. Van Der Linden, G. Kortuem, G. Dewsbury, D. Mills, P. Boyden, Ubicomp for animal welfare: envisioning smart environments for kenneled dogs, in: Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing, ACM, pp. 117–128.

[20] A. Zamansky, D. van der Linden, S. Baskin, Pushing boundaries of RE: Requirement elicitation for non-human users, in: Requirements Engineering Conference (RE), 2017 IEEE 25th International, IEEE.

[21] C. Mancini, R. Harris, B. Aengenheister, C. Guest, Re-centering multispecies practices: a canine interface for cancer detection dogs, in: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, ACM, pp. 2673–2682.

[22] C. L. Robinson, C. Mancini, J. Van Der Linden, C. Guest, R. Harris, Canine-centered interface design: supporting the work of diabetes alert dogs, in: Proceedings of the 32nd annual ACM conference on Human factors in computing systems, ACM, pp. 3757–3766.

[23] F. French, C. Mancini, H. Sharp, Designing interactive toys for elephants, in: Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play, ACM, pp. 523–528.

[24] H. Wirman, Games for/with strangers-captive orangutan (pongo pygmaeus) touch screen play, Antennae (2014).

[25] S. Baskin, S. Anavi-Goffer, A. Zamansky, Serious games: Is your user playing or hunting?, in: International Conference on Entertainment Computing, Springer, pp. 475–481.

[26] S. Baskin, A. Zamansky, The player is chewing the tablet!: Towards a systematic analysis of user behavior in animal-computer interaction, in: Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play, ACM, pp. 463–468.

[27] A. Zamansky, A. Roshier, C. Mancini, E. C. Collins, C. Hall, K. Grillaert, A. Morrison, S. North, H. Wirman, A report on the first international workshop on research methods in animal-computer interaction, in: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, Denver, CO, USA, May 06-11, 2017, Extended Abstracts., pp. 806–815.

[28] P. Pongrácz, V. Ujvári, T. Faragó, Á. Miklósi, A. Péter, Do you see what i see? the difference between dog and human visual perception may affect the outcome of experiments, Behavioural Processes 140 (2017) 53–60.

[29] F. French, C. Mancini, H. Sharp, Exploring research through design in animal computer interaction, in: Proceedings of the Fourth International Conference on Animal-Computer Interaction, ACI2017, ACM, 2017, pp. 2:1–2:12.

[30] R. Gupfinger, M. Kaltenbrunner, Sonic experiments with grey parrots: A report on testing the auditory skills and musical preferences of grey parrots in captivity, in: Proceedings of the Fourth International Conference on Animal-Computer Interaction, ACM.

[31] S. Lawson, B. Kirman, C. Linehan, T. Feltwell, L. Hopkins, Problematising upstream technology through speculative design: The case of quantified cats and dogs, in: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, CHI '15, ACM, New York, NY, USA, 2015, pp. 2663–2672.

[32] G. Tami, A. Gallagher, Description of the behaviour of domestic dog (canis familiaris) by experienced and inexperienced people, Applied Animal Behaviour Science 120 (2009) 159–169.

[33] A. Zamansky, D. van der Linden, S. Baskin, V. Kononova, Is my dog "playing" tablet games?: Exploring human perceptions of dog-tablet interactions, in: Proceedings of the Annual Symposium on Computer-Human Interaction in Play, CHI PLAY '17, ACM, New York, NY, USA, 2017, pp. 477–484.

[34] A. A. Cardenas, S. Amin, S. Sastry, Secure control: Towards survivable cyber-physical systems, in: Distributed Computing Systems Workshops, 2008. ICDCS'08. 28th International Conference on, IEEE, pp. 495–500.

[35] B. Cid, R. d. C. d. Costa, D. d. A. Balthazar, A. M. Augusto, A. S. Pires, F. A. Fernandez, Preventing injuries caused by radiotelemetry collars in reintroduced red-rumped agoutis, dasyprocta leporina (rodentia: Dasyproctidae), in atlantic forest, southeastern brazil, Zoologia (Curitiba) 30 (2013) 115–118.

[36] M. Stead, P. Coulton, Old, sick and no health insurance.: Will you need a permit to use your home-made health wearable?, in: Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems, ACM, pp. 101–105.

[37] P. Zeile, B. Resch, J.-P. Exner, G. Sagl, Urban emotions: benefits and risks in using human sensory assessment for the extraction of contextual emotion information in urban planning, in: Planning support systems and smart cities, Springer, 2015, pp. 209–225.

[38] B. Wolf, J. Polonetsky, K. Finch, A practical privacy paradigm for wearables, Future of Privacy Forum (FPF) (2016).

[39] M. R. Langley, Hide your health: Addressing the new privacy problem of consumer wearables, Geo. LJ 103 (2014) 1641.

[40] V. G. Motti, K. Caine, Users privacy concerns about wearables, in: International Conference on Financial Cryptography and Data Security, Springer, pp. 231–244.

[41] A. Marrington, D. Kerr, J. Gammack, Managing Security Issues and the Hidden Dangers of Wearable Technologies, IGI Global, 2016.

[42] R. Clarke, Person location and person tracking-technologies, risks and policy implications, Information Technology & People 14 (2001) 206–231.

[43] Z. Butler, P. Corke, R. Peterson, D. Rus, From robots to animals: virtual fences for controlling cattle, The International Journal of Robotics Research 25 (2006) 485–508.

[44] R. Lockwood, G. R. Hodge, The tangled web of animal abuse: The links between cruelty to animals and human violence, Humane Society News, Summer (1986) 10–15.

[45] P. Beirne, For a nonspeciesist criminology: Animal abuse as an object of study, Criminology 37 (1999) 117–148.

[46] A. Cavoukian, et al., Privacy by design: The 7 foundational principles. implementation and mapping of fair information practices, Information and Privacy Commissioner of Ontario, Canada (2009).

[47] F. T. Commission, et al., Protecting consumer privacy in an era of rapid change: Recommendations for businesses and policymakers, https://www.ftc.gov/reports/protecting-consumer-privacy-era-rapid-change-recommendations-businesses-policymakers, 2012. Online; accessed 04 December 2017.

[48] I. File, Proposal for a regulation of the european parliament and of the council on the protection of individuals with regard to the processing of personal data and on the free movement of such data (general data protection regulation), 2012.

[49] M. Birnhack, E. Toch, I. Hadar, Privacy mindset, technological mindset, Jurimetrics 55 (2014) 55.

[50] I. Hadar, T. Hasson, O. Ayalon, E. Toch, M. Birnhack, S. Sherman, A. Balissa, Privacy by designers: software developers privacy mindset, Empirical Software Engineering (2017) 1–31.

[51] J. van Rest, D. Boonstra, M. Everts, M. van Rijn, R. van Paassen, Designing privacy-by-design, in: Annual Privacy Forum, Springer, pp. 55–72.

[52] B. Craggs, A. Rashid, Smart cyber-physical systems: beyond usable security to security ergonomics by design, in: Proceedings of the 3rd International Workshop on Software Engineering for Smart Cyber-Physical Systems, IEEE Press, pp. 22–25.